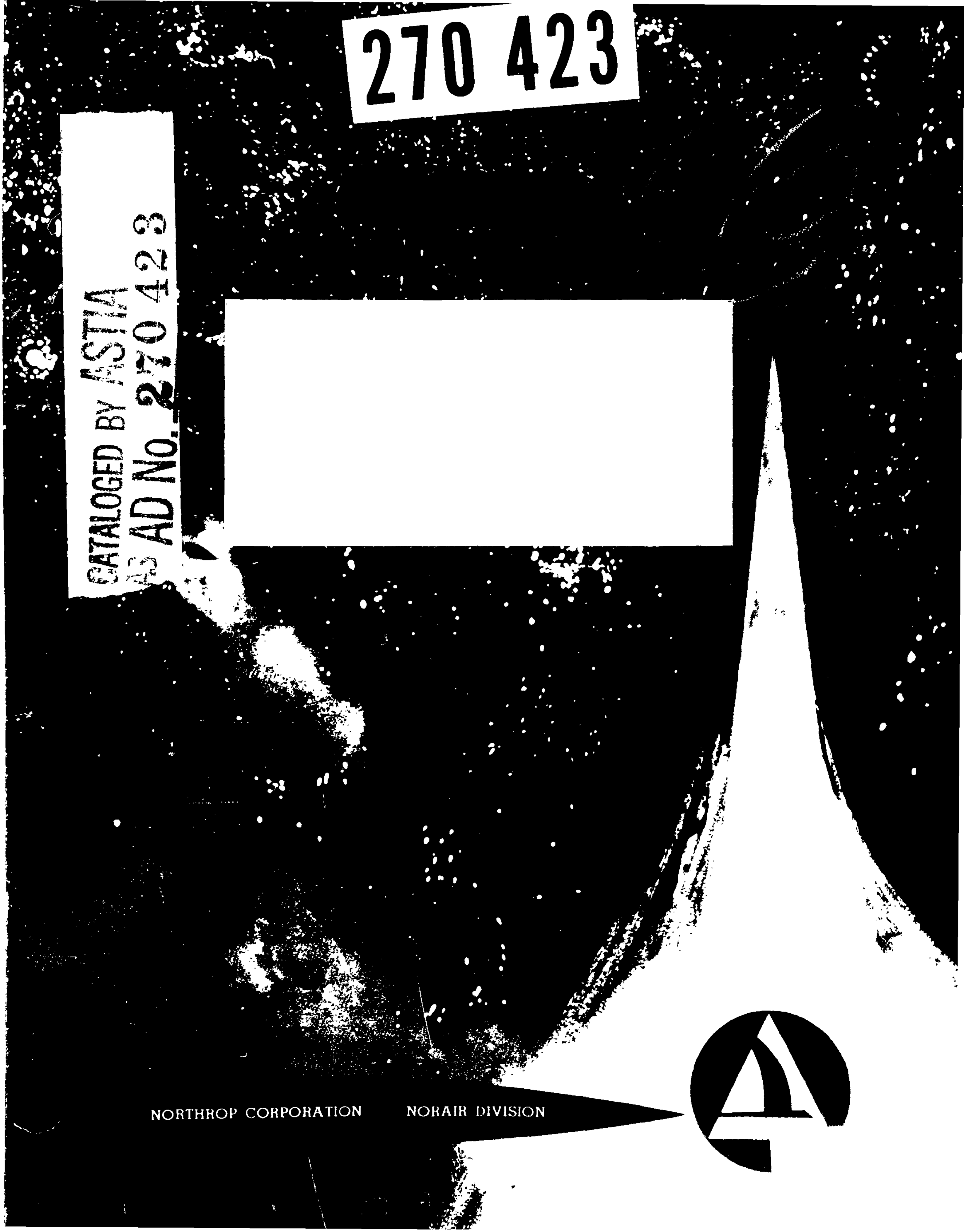

NORTHROP CORPORATION NORAIR DIVISION

NORTHROP AIRCRAFT, INC.

NORTHROP DIVISION

REPORT NO. NOR-59-396

PROPERTIES AND HEAT TREATMENT OF AM 350 STEEL

15 July 1959

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REVISIONS

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FORM 20-7A
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1. INTRODUCTION

AM 350, one of the newer high strength corrosion resistant steels, is sensitive to small variations in chemistry and heat treatment, and wide variations in its mechanical properties were encountered in material produced prior to 1956. It was the object of this work to verify the producer's claims that the material has been improved and will consistently meet the mechanical properties called for in applicable specifications; to verify the recommended heat treatment temperatures, times, and tolerances; and to obtain room- and elevated-temperature test data for use in establishing design allowables.

2. CONCLUSIONS

2.1 All material tested met the requirements of Specifications NAI-1149 and AMS 5548, although considerable variation in mechanical properties was found in sheets from different heats. The properties determined for different locations in individual sheets showed no significant variation.

2.2 The recommended heat treatment tolerances are satisfactory for developing the specification minimum properties. The "trigger" anneal treatment is the most critical for developing maximum properties, and a more extensive study of it should be undertaken.

2.3 The guaranteed and specification minima of 150 ksi yield strength, 185 ksi ultimate strength, and 10 percent elongation are considered satisfactory bases for the establishment of room temperature design allowables.

2.4 AM 350 does not have the high strength expected at elevated temperatures. Both PH 15-7 Mo and 17-7PH corrosion resistant steels in the RH 950 condition are stronger, the difference in tensile yield strength being approximately 30 ksi at 800 F and 10 ksi at 900 F. The compressive yield strength is much higher than its tensile yield strength, but still not as high as that of PH 15-7 Mo or 17-7PH. The difference in compressive and tensile yield strength of AM 350 persists to 1000 F.

2.5 AM 350 is not embrittled by exposure to temperatures up to 900 F. An increase in mechanical properties, both strength and elongation, was observed after exposure to elevated temperatures for 100 and 500 hours.

3. PROCEDURE

3.1 Specimen Preparation

Three sheets of AM 350 corrosion resistant steel, each from a different heat, were purchased from Allegheny Ludlum Steel Corporation for testing

in this program. The nominal dimensions of the sheets were 0.040 by 36 by 120 inches. The material was supplied in the H-1900 condition. Certified chemical composition and mechanical properties reported by the vendor are shown in Table I.

All specimens were taken with the length parallel to the rolling direction of the sheet. Nine tensile specimens used to verify the reliability of the material were taken from the following locations in each sheet: one from each corner, one from the center of each edge, and one from the center. Specimens for the remainder of the tests were taken at random locations.

Three tensile specimens from each sheet were heat treated to Condition L-1710 (heat to 1710 F ± 5 for 30 minutes, air cool to room temperature). The remainder of the specimens, except those to be used for heat treatment verification, were heat treated to Condition SCT-185 as recommended (heat to 1710 F ± 5 for 30 minutes, air cool to room temperature; liquid cool to -100 to 110 F for 3 hours; heat to 850 F ± 5 for 3 hours). Two tensile specimens from each sheet were heat treated to Condition SCT-185 with one variation in the procedure, as shown in Table II. All specimens were mechanically descaled prior to testing.

3.2 Tensile Tests

Tensile tests were performed on a Baldwin-Lima-Hamilton 5000 pound capacity testing machine and in accordance with Federal Test Method Standard No. 151, Method 211.1, specimen F2. Specimens were 8 inches long, with a 2 inch gage length 1/2 inch wide, and were loaded by means of 1/2 inch pins inserted through holes in the grip sections. Autographically recorded load-strain curves were used for calculation of yield strength and modulus of elasticity. The test equipment and fixtures are fully described in Report No. NAI-57-246 (Reference 1).

Twelve specimens from each sheet, three heat treated to Condition L-1710 and nine to Condition SCT-185, were tested at room temperature to verify reliability and uniformity of the material and establish conformance with the mechanical property requirements of Specification NAI-1149 and AMS 5548. The two specimens from each sheet that had been subjected to each heat treatment variation were also tested at room temperature.

Elevated temperature tensile tests were performed in triplicate at 600 F, 800 F, 900 F, and 1000 F on specimens prepared from Sheets 7 and 9. Sheet 7 was selected because it had the lowest room temperature strength and Sheet 9 because of its marginal elongation. A forced-air, box-type furnace was used to heat the specimens, which were soaked at temperature for 30 minutes prior to testing. The temperature during soaking and testing was held to within ± 5 F of that specified. An extensometer modified for high temperature use was used to record strain measurements.

To determine the effects of elevated temperature exposure, two specimens from each sheet were tested at room temperature after being heated for 100 hours and 500 hours in a forced-air electric furnace at 700 F, 800 F, and 900 F.

3.3 Compression Tests

Standard 1 by 3 inch compression specimens were tested in an NAA-type compression fixture in which the specimen is supported in a vertical position by steel leaves. The strain in the middle 2 inch section was recorded by means of a compressometer. The test equipment and fixtures are described in Reference 1. Load-strain curves were used for yield strength and modulus of elasticity calculations.

Compression tests were performed on a Baldwin-Tate-Emory 120,000 pound capacity testing machine at room temperature and at 600 F, 800 F, 900 F, and 1000 F on three specimens from each sheet. The forced-air, box-type furnace was used in elevated temperature tests. Specimens were soaked for 30 minutes, and the temperature was held within ± 5 F of that specified during soaking and testing.

3.4 Hardness Tests

Rockwell hardness was determined on tensile specimens used in establishing specification conformance and verifying heat treatment procedures. Hardness was determined on a Wilson Hardness Tester, Model JR.

4. RESULTS

4.1 Room Temperature Tensile Properties

The room temperature tensile properties for both the L-1710 and SCT-185 conditions are listed in Table III. All sheets met the requirements of Specification NAI-1149 for Condition L-1710, although Sheet 9 was marginal in ultimate strength and elongation. All sheets met specification requirements for the SCT-185 condition, having average properties of 204 ksi ultimate strength, 170 ksi yield strength, and elongation between 10.0 and 18.5 per cent. The total variation of the material tested was 10 ksi for both yield and ultimate strength.

4.2 Effects of Heat Treatment Variations

Tensile properties of material subjected to variations in heat treatment are given in Table IV. All heat treatments investigated produced acceptable properties. Figure 1 is a graph showing the effect of the annealing treatment, and Figure 2 shows the effect of the tempering temperature.

Ultimate and yield strengths varied unpredictably with the annealing temperature. Since each sheet reacted differently, a single temperature could not be found to produce the best properties in all three sheets. From the observed data it appears that temperatures near 1700 F produced the most uniform results. Decreasing the annealing time from 30 to 10 minutes caused only a slight loss in strength for the material tested, but for other heats a greater loss in strength might result.

After the 1710 F trigger anneal, the material must be directly subzero cooled to -100 F. Higher temperature, shorter time at temperature, and a delay between annealing and cooling all caused loss of strength. According to DMIC Report 111 (Reference 2), holding at -100 F for longer than the recommended 3 hours results in higher strengths with reduced ductility.

Tempering as recommended at 850 F for 3 hours produced the maximum hardening. Tempering at 900 F gave an increase of 3 per cent in elongation, with an accompanying loss of 10 ksi in strength.

4.3 Hardness/Strength Correlation

Rockwell hardness measurements are included in Tables III and IV. A satisfactory correlation between hardness and strength could not be found. As is true with other stainless steels, a plot of strength versus hardness gives a scatterband, as shown in Figure 3.

4.4 Elevated Temperature Tensile Properties

The results of elevated temperature tensile tests are presented in Table V and shown graphically in Figure 4. Yield and ultimate strength decreased gradually with increase in temperature up to 800 F, where the loss in yield strength became more rapid with further increase in temperature. Yield strength decreased more rapidly than ultimate strength. Young's modulus decreased gradually with increasing temperature. Elongation decreased to a minimum of 5 per cent at 600 F, then increased at higher temperatures. Sheet 9 showed another loss of elongation at 100 F, while the elongation of Sheet 7 continued to increase. The reason for this behavior is unknown.

4.5 Effects of Elevated Temperature Exposures

Results of room temperature tensile tests after exposure to elevated temperatures are given in Table VI and presented graphically in Figures 5 and 6. All strengths were above the specification minimum requirements. Except for Sheet 9, the tensile properties were increased or unchanged. Sheet 9 exhibited a small loss in ultimate strength when exposed to 800 F and 900 F for 100 hours, but behaved similarly to the other sheets under all other exposure conditions. Elongation was slightly reduced for all sheets when specimens were exposed to 800 F for 500 hours, or to 900 F for 100 hours or 500 hours. All elongation measurements were above the 10 per cent specification minimum, however.

4.6 Compressive Properties

Results of room- and elevated-temperature compression tests are given in Table VII and Figure 7. The compressive yield strength behavior with elevated temperature was similar to that of tensile yield strength, but 30 ksi higher. Compressive modulus of elasticity decreased slightly with increasing temperature up to 800 F, where it began to decrease rapidly.

5. DISCUSSION

AM 350, a semiaustenitic steel, is austenitic at room temperature after annealing at 1950 F. In this condition, the M_s is below -100 F. In order to transform the austenite to martensite, the M_s and M_f must be adjusted to higher temperatures. The M_s and M_f are adjusted at a temperature which will precipitate enough carbide to raise the M_s and M_f but leave enough carbon in the austenite to give reasonably strong martensite. Further increase in strength is obtained by a controlled precipitation of the constituents in solution in the martensite.

The 1950 F anneal is used to give a soft, easily formed material. Temperatures higher than 1950 F give larger grains and increased amounts of delta ferrite, both being detrimental to strength. The delta ferrite is soft and ductile and is not affected by subsequent heat treating operations. Therefore, large amounts of delta ferrite result in lower strengths. Large grain size tends to cause uneven distribution of carbides precipitated during subsequent treatments, which may result in lower strength and corrosion resistance. Annealing at lower temperatures gives uneven distribution of carbides and less stress relief than annealing at 1950 F. Lower annealing temperatures may also result in less stable austenite, giving lower formability.

The amount of delta ferrite formed in AM 350 is partially dependent on chemical composition and annealing temperature. Different heats of material annealed at 1950 F may have varying amounts of delta ferrite formed (5 to 15 per cent) owing to slight variations in chemical composition, which is one possible cause for variation in strength between different heats of material.

To harden AM 350, the austenite composition must be adjusted to raise the M_s and M_f temperatures. Heating to 1710 F for short times raises the M_s to just above room temperature and the M_f to -100 F. When AM 350 is heated to 1710 F, carbides are precipitated from the austenite into the austenite-delta-ferrite interfaces. The austenite retains approximately 0.05 per cent carbon at this temperature. Variations in the balance of other alloying elements may result in a change of the M_s and M_f temperatures. It is possible, then, to obtain full transformation of austenite at -100 F in one heat of material but only partial transformation in another, resulting in larger quantities of retained

austenite. Greater amounts of retained austenite decrease the yield strength primarily. As shown in Figure 1, the same annealing temperature is not ideal for all heats of AM 350. The "trigger" anneal is the most critical operation in heat treating AM 350 and determines to a great extent the strength of the fully heat treated material. Variation of chemistry is not the only cause of variation in the mechanical properties of AM 350. Certified reports from the vendor show a variation of 15 ksi tensile strength in two sheets purchase from the same heat; as only one of these sheets was tested in this program, no explanation can be given for the variation.

Following the "trigger" anneal, cooling to -100 F for 3 hours completes the austenite-to-martensite transformation. Loss of strength is caused by delaying the subzero treatment or by cooling to a temperature above -100 F. Cooling to -100 F is necessary for complete transformation, and any temperature above this will give increased amounts of retained austenite. Delaying the subzero treatment may result in austenite stabilization, i.e., the austenite-to-martensite transformation becomes sluggish, giving more retained austenite. Holding for longer time at -100 F is reported to give higher strength but lower ductility, because of further austenite transformation (Reference 2). Three hours is chosen as giving the best combination of strength and ductility.

The increase in strength with exposure to elevated temperatures, particularly to 800 F for 500 hours, is not fully understood but is thought to be due to precipitation of a hardening phase, possibly a chromium-rich ferrite. The increase in elongation after exposure at 700 F is also unexplained, although certainly some stress relief is taking place.

6. REFERENCES

1. McCarthy, W. H., "Short Time Elevated Temperature Mechanical Properties of 6Al-4V Titanium Alloy Sheet," Report No. NAI-57-246, 21 February 1957.

2. Ludwigzon, D. C., and Hall, A. M., "The Physical Metallurgy of Precipitation-hardenable Stainless Steels," DMIC Report 111, April 20, 1959.

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TABLE I. CHEMICAL COMPOSITION AND MECHANICAL PROPERTIES OF AM 350 STEEL REPORTED BY ALLEGHENY LUDLUM STEEL CORPORATION

	Requirement	Sheet 3 Heat 35204	Sheet 7 Heat 79277	Sheet 9 Heat 79650
Composition	AMS 5548			
Carbon, %	0.08 - 0.12	0.094	0.091	0.089
Manganese, %	0.50 - 1.25	1.02	0.76	0.76
Phosphorous, %	0.040 max	0.022	0.020	0.018
Sulfur, %	0.030 max	0.013	0.022	0.017
Silicon, %	0.50 max	0.37	0.22	0.24
Chromium, %	16.0 - 17.0	16.78	16.78	16.37
Nickel, %	4.0 - 5.0	4.45	4.53	4.11
Molybdenum, %	2.5 - 3.25	2.95	2.93	2.73
Nitrogen, %	0.07 - 0.13	0.10	0.12	0.090
Condition H-1900	AMS 5548			
Yield strength, ksi	75.0 max	73.6	67.7	49.8
Ultimate strength, ksi	180.0 max	151.8	146.3	169.9
Elongation in 2 in., %	20.0 min	47.0	44.0	28.5
Rockwell hardness	B 95 - 100	B 93 - 96	B 93	B 95
Cold bend, 180°	2T	OK	OK	OK
Condition L-1750	NAI-1149			
Yield strength, ksi	120 max	43.0	44.4	66.3
Ultimate strength, ksi	200 max	166.9	186.4	197.7
Elongation in 2 in., %	8.0 min	15.0	13.0	9.0
Rockwell hardness	—	C 39.5	C 39.5	C 42.5
Condition SCT-185	AMS 5548			
Yield strength, ksi	150.0 min	180.8	167.7	175.9
Ultimate strength, ksi	185.0 min	200.8	204.6	214.6
Elongation in 2 in., %	10.0 min	12.0	10.0	11.0
Rockwell hardness	C 38 - 48	—	C 47	C 47

TABLE II. VARIATIONS ON SCT-185 HEAT TREATMENT

Designation	Anneal	Transform	Temper
A	Standard: 1710 F ± 5 for 30 minutes, air cool	Standard: -100 to -110 F for 3 hours	Standard: 850 F ± 5 for 3 hours, air cool
B	1685 F ± 5	Standard	Standard
C	1700 F ± 5	Standard	Standard
D	1725 F ± 5	Standard	Standard
E	1750 F ± 5	Standard	Standard
F	1710 F ± 5 for 10 minutes	Standard	Standard
G	Standard	-80 to -90 F	Standard
H	Standard	-100 to -110 F for 90 minutes	Standard
J	Standard	-100 to 110 F for 3 hours 7 days after annealing	Standard
P	Standard	Standard	825 F ± 5
Q	Standard	Standard	875 F ± 5
R	Standard	Standard	900 F ± 5
S	Standard	Standard	950 F ± 5
T	Standard	Standard	850 F ± 5 for 90 minutes

TABLE III. ROOM TEMPERATURE TENSILE PROPERTIES OF AM 350 STEEL IN CONDITIONS L-1710 AND SCT-185

Test No.	Sheet 3 Fty 0.02% Offset ksi	Sheet 3 Fty 0.2% Offset ksi	Sheet 3 Ftu ksi	Sheet 3 Elong in 2 in. %	Sheet 3 E 10^6 psi	Sheet 3 Hardness R_C	Sheet 7 Fty 0.02% Offset ksi	Sheet 7 Fty 0.2% Offset ksi	Sheet 7 Ftu ksi	Sheet 7 Elong in 2 in. %	Sheet 7 E 10^6 psi	Sheet 7 Hardness R_C	Sheet 9 Fty 0.02% Offset ksi	Sheet 9 Fty 0.2% Offset ksi	Sheet 9 Ftu ksi	Sheet 9 Elong in 2 in. %	Sheet 9 E 10^6 psi	Sheet 9 Hardness R_C
Condition L-1710																		
L1	36.8	48.0	166.1	16.0	26.5	40.0	35.4	44.0	186.6	13.0	28.2	40.5	53.6	69.1	195.7	8.5	28.8	42.5
L2	33.4	40.0	165.0	14.5	26.1	39.5	34.9	45.1	188.4	12.5	28.6	39.0	49.5	64.7	198.1	9.0	28.8	42.5
L3	34.5	40.9	168.6	15.0	26.4	39.0	35.0	44.2	184.3	13.5	30.6	39.0	52.2	65.0	199.3	9.5	27.9	42.5
Avg	34.9	43.0	166.6	15.2	26.3	39.5	35.1	44.4	186.4	13.0	29.1	39.5	51.8	66.3	197.7	9.0	28.5	42.5
Condition SCT-185																		
A1	105.2	169.3	206.5	18.0	27.8	46.5	118.8	165.7	199.3	13.0	27.3	47.0	141.9	173.1	206.6	10.0	27.8	48.0
A2	110.4	171.3	205.7	17.5	25.9	46.5	121.6	165.2	198.4	13.0	26.8	46.0	139.2	171.1	204.1	11.0	27.1	46.5
A3	111.9	171.9	208.8	18.0	28.0	49.0	125.0	165.1	199.1	16.0	26.9	46.0	139.0	172.2	206.0	10.0	28.0	46.5
A4	119.3	166.9	203.9	19.0	26.1	45.0	128.2	169.9	203.5	14.0	27.6	46.0	140.1	171.8	205.4	9.5	27.7	45.5
A5	105.3	163.2	203.6	19.0	27.5	47.0	128.3	167.6	200.9	14.5	26.2	45.0	141.4	172.1	204.4	10.0	27.1	46.5
A6	114.7	171.5	209.0	18.0	27.5	46.0	125.2	166.1	200.4	18.0	26.1	46.0	142.0	172.9	206.3	11.0	27.9	46.5
A7	115.8	171.4	206.7	17.5	26.7	47.0	125.6	167.2	199.9	16.0	26.9	45.0	144.2	173.8	208.1	12.5	27.4	46.5
A8	122.7	170.8	207.4	18.5	26.2	47.0	123.9	166.7	199.6	14.0	27.0	45.5	141.7	173.6	207.4	13.0	27.4	46.5
A9	114.4	170.4	206.8	18.5	26.3	47.0	129.1	169.9	201.0	12.5	25.5	46.0	143.8	174.4	207.8	11.0	27.9	46.5
Avg	113.4	169.6	206.5	18.2	26.9	46.8	125.1	167.0	200.2	13.6	26.7	45.8	141.5	172.3	206.2	10.9	27.6	46.6

TABLE IV. ROOM TEMPERATURE TENSILE PROPERTIES OF AM 350 STEEL SUBJECTED TO VARIATIONS IN SCT-185 HEAT TREATMENT

Heat-Treatment Variation	Test No.	Sheet 3					Sheet 7					Sheet 9				
		Fty 0.2% Offset ksi	Ftu ksi	Elong in 2 in. %	E 10^6 psi	Hardness R_C	Fty 0.2% Offset ksi	Ftu ksi	Elong in 2 in. %	E 10^6 psi	Hardness R_C	Fty 0.2% Offset ksi	Ftu ksi	Elong in 2 in. %	E 10^6 psi	Hardness R_C
A. Standard (from Table III), 1710F Anneal for 30 minutes	Min	163.2	203.6	17.5	25.9	45.0	165.1	198.4	12.5	25.5	45.0	171.1	204.1	9.5	27.1	45.5
	Max	171.9	209.0	19.0	28.0	49.0	169.9	203.5	18.0	27.6	47.0	174.4	208.1	13.0	28.0	48.0
	Avg	169.6	206.5	18.2	26.9	46.8	167.0	200.2	13.6	26.7	45.8	172.8	206.2	10.9	27.6	46.6
B. 1685F Anneal	B1	176.4	209.5	17.0	26.3	46.5	173.9	203.4	12.0	27.8	46.0	174.0	206.0	10.0	27.8	45.5
	B2	173.3	208.7	18.0	27.0	47.5	172.9	205.6	12.5	29.0	46.0	172.0	205.8	11.0	29.1	46.5
	Avg	174.8	209.1	17.5	26.6	47.0	173.4	204.5	12.2	28.4	46.0	173.0	205.9	10.5	28.4	46.0
C. 1700F Anneal	C1	166.9	199.7	17.5	26.8	45.0	165.9	197.6	13.0	27.0	45.5	173.7	207.6	11.0	28.2	46.0
	C2	166.8	205.4	16.5	28.8	47.0	166.7	199.3	15.0	28.6	46.0	172.3	204.7	9.0	27.7	45.5
	Avg	166.8	202.6	17.0	27.8	46.0	166.3	198.4	14.0	27.8	45.8	173.0	206.2	10.0	28.0	45.8
D. 1725F Anneal	D1	149.5	198.4	18.5	28.6	46.0	165.9	204.5	17.0	28.0	47.0	171.9	208.1	10.5	28.0	47.0
	D2	151.7	199.6	20.5	28.0	45.5	165.4	203.0	18.0	27.4	46.0	173.2	208.3	10.5	28.1	47.0
	Avg	150.6	199.0	19.5	28.3	45.8	165.6	203.8	17.5	27.7	46.5	172.6	208.2	10.5	28.0	47.0
E. 1750F Anneal	E1	150.7	198.9	19.5	28.0	45.0	157.1	197.8	21.5	24.7	46.0	174.4	211.2	11.0	28.3	47.5
	E2	150.2	199.2	23.0	28.6	45.0	159.1	197.6	20.5	25.3	45.0	176.4	211.4	9.0	27.7	47.5
	Avg	150.4	199.0	21.2	28.3	45.0	158.1	197.7	21.0	25.0	45.5	175.4	211.3	10.0	28.0	47.5
F. 1710F Anneal for 10 minutes only	F1	164.4	202.7	20.5	24.8	45.5	167.6	201.2	16.0	26.3	45.0	174.4	208.4	12.0	27.7	46.5
	F2	164.8	203.2	18.5	27.7	46.0	165.5	202.4	18.0	28.3	45.5	174.2	209.1	11.0	28.3	47.0
	Avg	164.6	203.0	19.5	26.2	45.8	166.6	201.8	17.0	27.3	45.2	174.3	208.8	11.5	28.0	46.8
G. -80F to -90F Transformation	G1	153.5	194.6	19.0	28.4	45.0	157.7	188.8	17.5	26.4	44.5	172.2	205.2	10.0	27.7	45.5
	G2	158.8	195.1	16.5	28.2	44.5	160.0	190.0	18.0	25.4	44.5	171.0	204.0	10.0	27.6	46.5
	Avg	156.2	194.8	17.8	28.3	44.8	158.8	189.4	17.8	25.9	44.5	171.6	204.6	10.0	27.6	46.0
H. -100F to -110F Transformation for 90 minutes only	H1	152.7	197.4	21.5	28.6	46.0	155.2	192.7	19.5	26.9	45.5	168.8	201.5	13.0	26.5	45.0
	H2	151.9	197.0	22.0	27.9	46.0	151.5	192.2	20.0	28.0	45.0	167.0	202.0	11.5	27.9	46.0
	Avg	152.3	197.2	21.8	28.2	46.0	153.4	192.4	19.8	27.4	45.2	167.9	201.8	12.2	27.2	45.5
J. Transformation (standard) 7 days after annealing	J1	157.7	194.3	23.0	26.3	--	154.8	189.3	17.5	26.8	--	166.8	200.1	10.0	28.1	--
	J2	158.8	199.0	23.5	26.9	--	157.3	189.3	18.5	26.4	--	165.7	200.6	12.0	27.9	--
	Avg	158.2	196.6	23.2	26.6	--	156.0	189.3	18.0	26.6	--	166.2	200.4	11.0	28.0	--

TABLE IV. ROOM TEMPERATURE TENSILE PROPERTIES OF AM 350 STEEL SUBJECTED TO VARIATIONS IN SCT-185 HEAT TREATMENT (continued)

Heat-Treatment Variation	Test No.	Sheet 3					Sheet 7					Sheet 9				
		Fty 0.2% Offset ksi	Ftu ksi	Elong in 2 in. %	E 10^6 psi	Hardness R_C	Fty 0.2% Offset ksi	Ftu ksi	Elong in 2 in. %	E 10^6 psi	Hardness R_C	Fty 0.2% Offset ksi	Ftu ksi	Elong in 2 in. %	E 10^6 psi	Hardness R_C
P. 825F Temper	P1	169.4	202.3	18.0	24.4	47.5	158.2	192.2	17.5	25.5	46.0	169.4	204.9	9.0	27.9	46.0
	P2	163.3	198.1	17.5	25.4	47.5	158.7	192.6	17.5	25.3	47.0	168.1	203.5	10.5	27.5	47.0
	Avg	166.4	200.2	17.8	24.9	47.5	158.4	192.4	17.5	25.4	46.5	168.8	204.2	9.8	27.7	46.5
Q. 875F Temper	Q1	167.8	198.7	20.0	22.8	46.0	157.9	189.9	21.0	25.8	46.5	168.2	199.6	10.0	27.5	45.5
	Q2	162.7	197.1	20.0	23.7	46.5	158.8	189.7	14.0	26.6	46.5	168.7	201.2	11.5	27.9	47.0
	Avg	165.2	197.9	20.0	23.2	46.2	158.4	189.8	17.5	26.2	46.5	168.4	200.4	10.8	27.7	46.2
R. 900F Temper	R1	--	192.3	19.0	26.6	44.5	157.7	189.4	20.0	26.4	45.5	167.0	195.9	11.0	27.3	45.0
	R2	156.6	195.4	19.0	27.6	45.0	161.2	190.5	17.5	26.5	44.5	165.5	195.9	15.0	27.5	46.0
	Avg	--	193.8	19.0	27.1	44.8	159.4	190.0	18.8	26.4	45.0	166.2	195.9	13.0	27.4	45.5
S. 950F Temper	S1	150.8	180.6	19.0	27.5	43.5	152.6	178.5	18.5	27.5	43.0	161.7	186.8	13.0	28.0	43.0
	S2	148.0	180.6	19.5	29.9	42.5	156.3	179.0	15.0	27.0	43.0	160.6	185.7	14.0	26.7	43.0
	Avg	149.4	180.6	19.2	28.7	43.0	154.4	178.8	16.8	27.2	43.0	161.2	186.2	13.5	27.4	43.0
T. 850F Temper for 90 minutes only	T1	164.0	197.7	20.0	24.7	46.5	156.5	190.8	15.0	26.4	46.5	166.9	203.5	10.0	28.4	47.0
	T2	159.5	197.4	18.5	26.8	47.5	157.9	191.8	16.5	26.7	47.0	168.4	204.2	13.0	27.8	46.5
	Avg	161.8	197.6	19.2	25.8	47.0	157.2	191.3	15.8	26.6	46.8	167.6	203.8	11.5	28.1	46.8

TABLE V. ELEVATED TEMPERATURE TENSILE PROPERTIES OF AM 350 STEEL

Test Temperature	Test No.	Sheet 7					Sheet 9				
		Fty 0.02% Offset ksi	Fty 0.2% Offset ksi	Ftu ksi	Elong in 2 in. %	E 10^6 psi	Fty 0.02% Offset ksi	Fty 0.2% Offset ksi	Ftu ksi	Elong in 2 in. %	E 10^6 psi
600F	V1	94.3	126.9	178.7	7.5	24.4	101.9	139.1	190.6	5.0	26.4
	V2	92.1	130.3	179.8	6.5	23.5	106.7	142.2	192.0	5.0	26.4
	V3	91.0	129.4	179.3	5.5	23.9	85.3	138.1	190.9	5.0	26.4
	Avg	92.5	128.9	179.3	6.5	23.9	98.0	139.8	191.2	5.0	26.4
800F	W1	81.0	117.8	175.3	9.5	23.4	91.0	126.7	183.0	10.5	25.4
	W2	75.1	115.6	172.3	10.0	22.7	83.9	122.7	180.4	10.0	23.2
	W3	74.5	114.1	173.0	10.0	22.7	88.1	127.6	183.1	10.0	23.6
	Avg	76.9	115.8	173.5	9.8	22.9	87.7	125.7	182.2	10.2	24.1
900F	X1	61.0	104.2	157.6	10.5	22.7	72.8	114.7	167.2	10.0	22.1
	X2	67.1	106.0	157.2	11.5	19.9	74.3	117.5	167.1	11.0	24.4
	X3	64.5	105.7	156.6	10.5	21.0	74.3	117.2	165.4	10.5	23.6
	Avg	64.2	105.3	157.1	10.8	21.2	73.8	116.5	166.6	10.5	23.4
1000F	Z1	48.3	82.1	106.0	8.5*	18.1	54.9	94.4	126.1	8.0	21.1
	Z2	52.6	81.5	105.6	16.0	21.5	50.6	91.9	125.7	8.0	20.4
	Z3	54.1	82.9	108.6	12.5	18.8	46.7	89.2	126.8	8.0	23.4
	Avg	51.7	82.2	106.7	14.2	19.5	50.7	91.8	126.2	8.0	21.8

* Specimen failed at location of extensometer screw; value excluded from average.

TABLE VI. ROOM TEMPERATURE TENSILE PROPERTIES OF AM 350 STEEL AFTER EXPOSURE TO ELEVATED TEMPERATURES

Exposure	Test No.	Sheet 3				Sheet 7				Sheet 9			
		Fty 0.2% Offset ksi	Ftu ksi	Elong in 2 in. %	E 10^6 psi	Fty 0.2% Offset ksi	Ftu ksi	Elong in 2 in. %	E 10^6 psi	Fty 0.2% Offset ksi	Ftu ksi	Elong in 2 in. %	E 10^6 psi
700F for 100 hr	K1	171.6	212.3	19.5	28.7	166.7	204.3	18.0	30.3	179.3	213.3	11.5	31.6
	K3	172.8	212.3	19.0	30.0	168.5	204.1	17.5	29.2	181.5	213.7	12.5	30.2
	Avg	172.2	212.3	19.2	29.4	167.6	204.2	17.8	29.8	180.4	213.5	12.0	30.9
700F for 500 hr	K2	177.8	216.3	19.5	28.3	171.5	204.8	18.0	28.5	176.3	209.4	13.0	29.9
	K4	178.6	216.5	20.0	28.0	168.6	203.7	17.0	28.7	178.6	209.5	13.0	29.3
	Avg	178.2	216.4	19.8	28.2	170.0	204.2	17.5	28.6	177.4	209.4	13.0	29.6
800F for 100 hr	M1	176.6	211.5	18.5	27.6	172.8	206.8	16.5	29.8	174.6	204.7	13.5	28.6
	M3	174.4	210.1	17.0	27.7	169.3	204.5	17.5	29.8	175.4	204.6	14.0	27.7
	Avg	175.5	210.8	17.8	27.6	171.0	205.6	17.0	29.8	175.0	204.6	13.8	28.2
800F for 500 hr	M2	185.1	218.4	13.0	28.9	190.3	221.6	14.5	30.3	191.4	217.7	11.0	30.8
	M4	184.6	218.9	15.5	29.9	188.7	213.6	16.0	30.0	180.2	215.6	12.0	30.2
	Avg	184.8	218.6	14.2	29.4	189.5	217.6	15.2	30.2	185.8	216.6	11.5	30.5
900F for 100 hr	N1	178.0	208.8	15.5	30.4	177.4	201.8	15.0	29.5	179.2	198.1	10.0	30.9
	N3	175.8	204.5	15.0	29.4	179.1	203.4	14.0	29.1	178.8	198.1	10.0	30.6
	Avg	176.9	206.6	15.2	29.9	178.2	202.6	14.5	29.3	179.0	198.1	10.0	30.8
900F for 500 hr	N2	175.5	211.6	12.0	28.4	172.5	204.1	11.5	29.2	183.0	206.4	9.5	30.9
	N4	175.5	212.9	11.5	30.6	181.3	211.7	12.0	31.3	186.2	209.1	10.5	30.9
	Avg	175.5	212.2	11.8	29.5	176.9	207.9	11.8	30.2	184.6	207.8	10.0	30.9

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TABLE VII. ROOM- AND ELEVATED-TEMPERATURE COMPRESSIVE PROPERTIES OF AM 350 STEEL

Test Temperature	Test No.	Sheet 3		Sheet 7		Sheet 9	
		Fcy 0.2% Offset ksi	E 10^6 psi	Fcy 0.2% Offset ksi	E 10^6 psi	Fcy 0.2% Offset ksi	E 10^6 psi
Room	A1	189.3	30.1	199.9	30.6	199.9	31.7
	A2	196.3	29.3	198.3	29.2	207.3	32.4
	A3	202.1	30.2	191.0	31.3	201.4	31.[illegible]
	Avg	195.9	29.9	196.4	30.4	202.9	31.7
600F	V1	160.0	26.3	162.8	26.3	173.5	28.1
	V2	162.5	27.5	164.0	27.9	172.9	29.0
	V3	168.4	27.5	160.3	28.2	170.2	29.2
	Avg	163.6	27.1	162.4	27.5	172.2	28.8
800F	W1	146.1	31.9	149.5	30.[illegible]	159.3	30.1
	W2	148.2	29.6	151.4	21.7	155.7	32.6
	W3	144.4	31.0	148.1	27.2	150.1	29.6
	Avg	146.2	30.8	149.7	26.4	155.0	30.8
900F	X1	129.5	22.9	134.4	26.3	147.1	27.1
	X2	134.6	23.5	135.3	26.8	143.7	25.6
	X3	129.0	24.0	136.0	25.1	145.0	24.0
	Avg	131.0	23.5	135.2	26.1	145.3	25.6
1000F	Z1	97.4	17.4	110.0	17.7	115.5	19.0
	Z2	107.7	17.5	112.0	19.4	122.7	20.0
	Z3	104.9	17.4	119.3	18.3	126.9	20.0
	Avg	103.3	17.4	114.1	18.5	121.7	19.7

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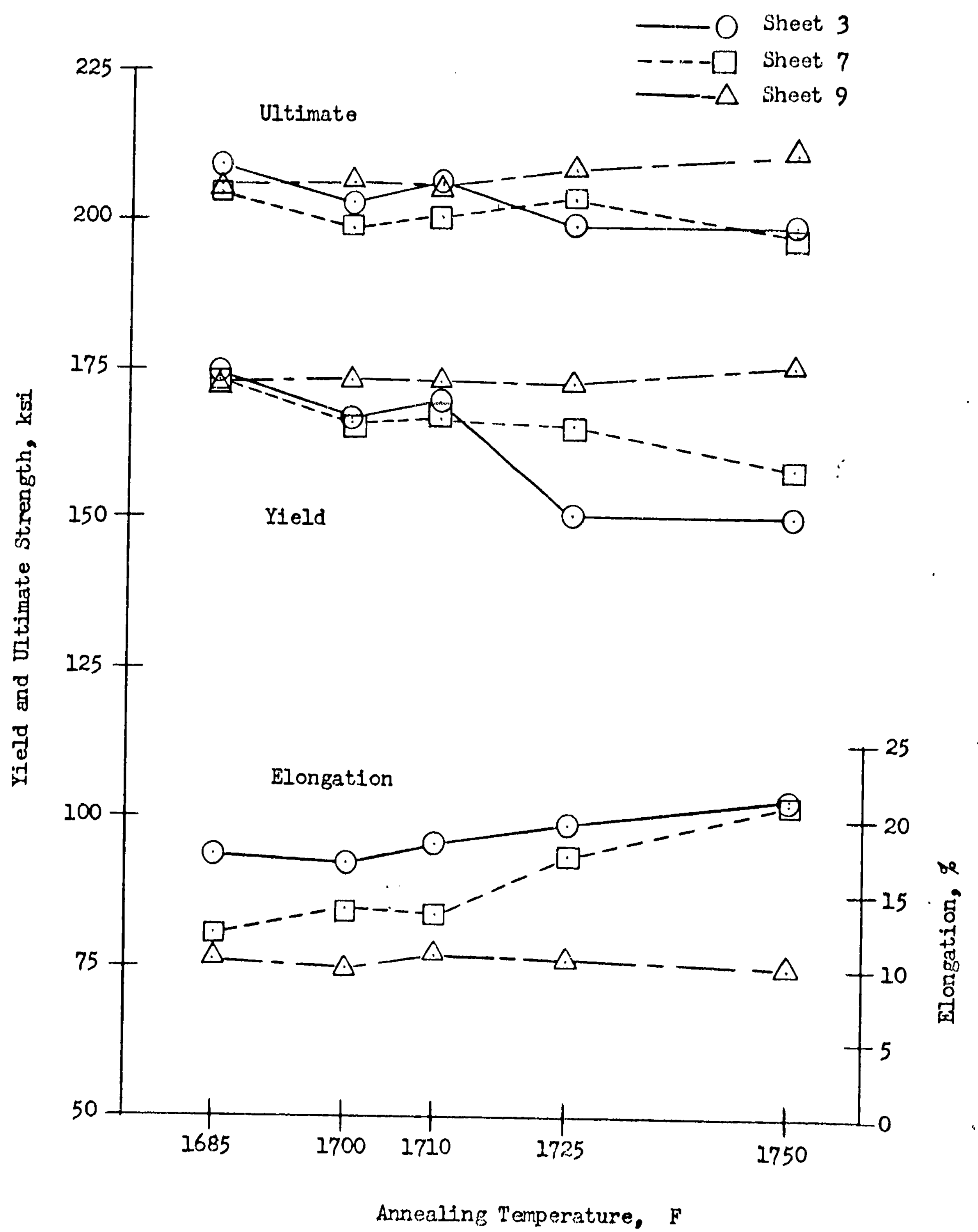
CHECKER		REPORT NO. NOR-59-396
DATE 15 July 1959 Rev. 28 November 1961	Figure 1. Effect of Annealing Temperature on Tensile Properties	MODEL



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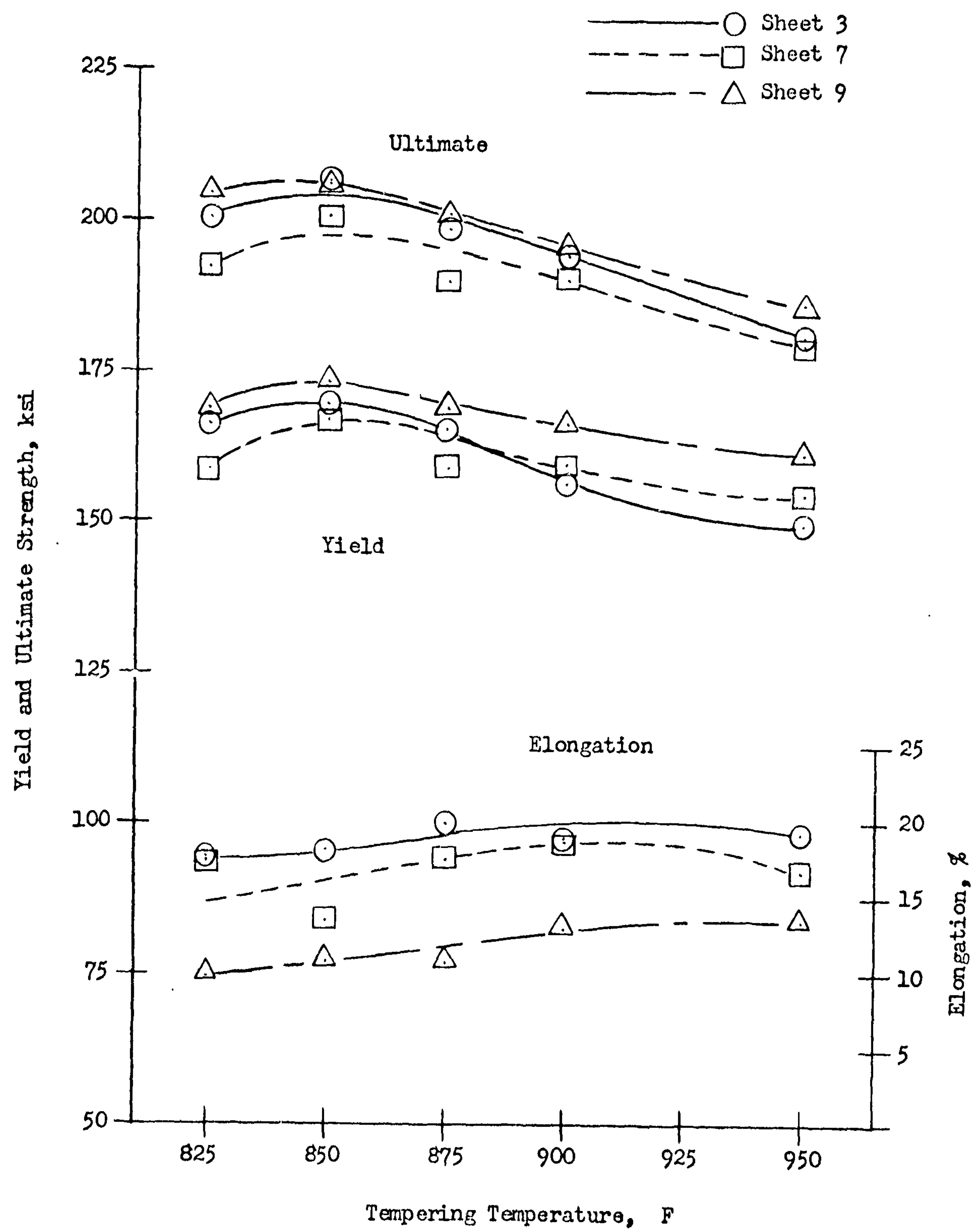
ENGINEER F. C. Kahlbaugh	NORTHROP AIRCRAFT, INC. NORTHROP DIVISION	PAGE 16
CHECKER		REPORT NO. NOR-59-396
DATE 15 July 1959 Rev.28 November 1961	Figure 2. Effect of Tempering Temperature on Tensile Properties	MODEL



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F. C. Kahlbaugh	NORTHROP AIRCRAFT, INC. NORTHROP DIVISION	17
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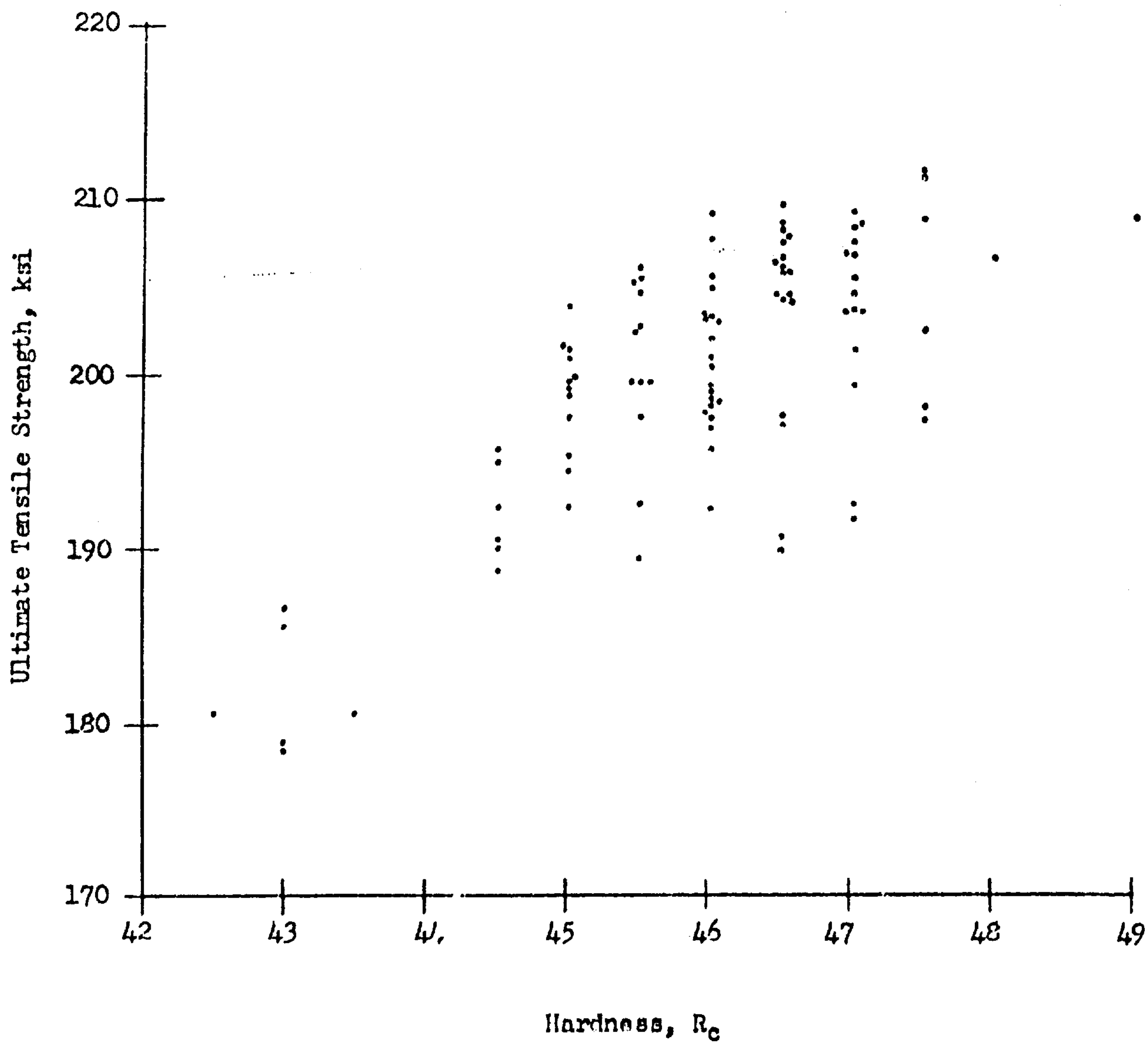

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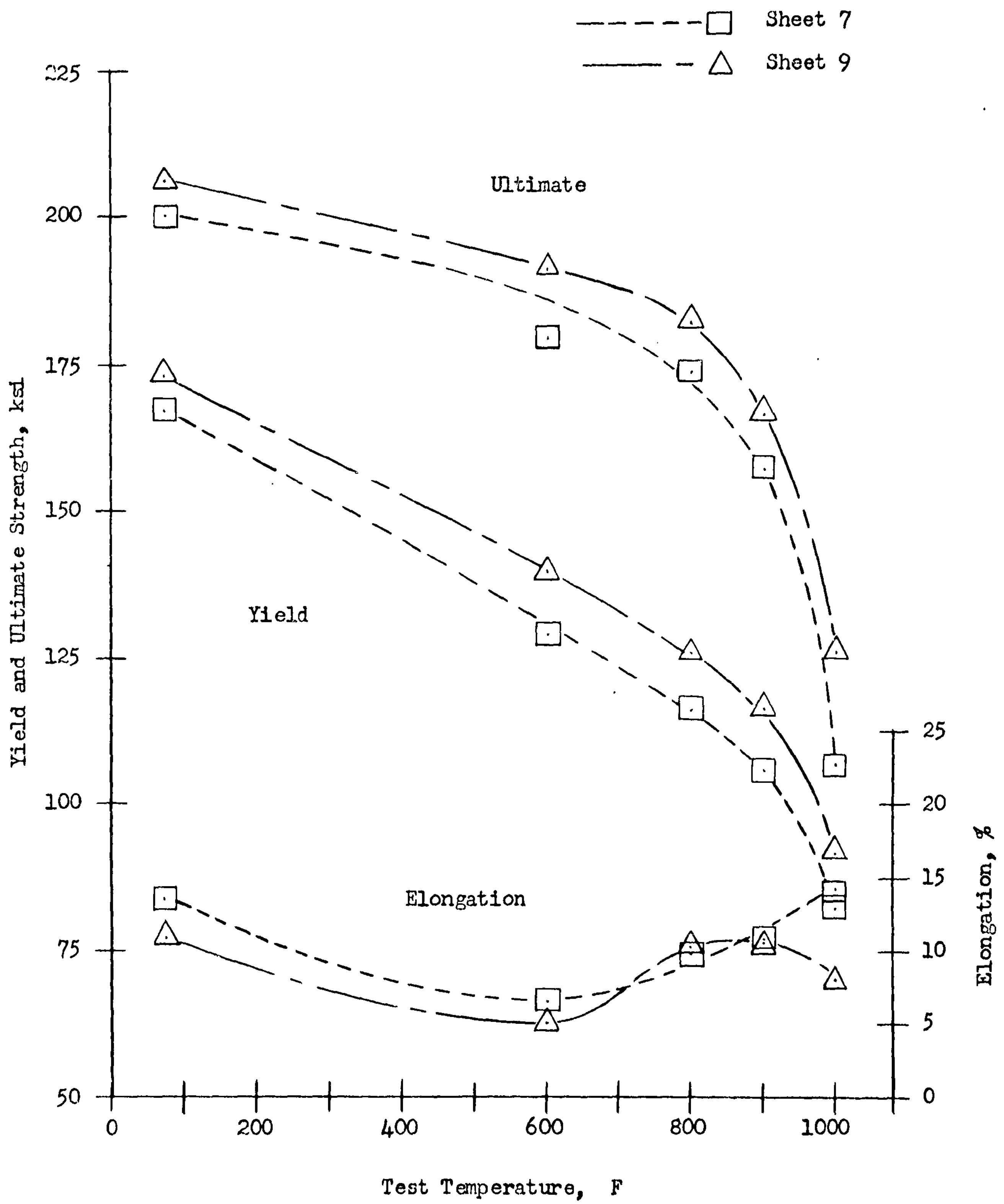
ENGINEER F. C. Kahlbaugh	NORTHROP AIRCRAFT, INC. NORTHROP DIVISION	PAGE 18
CHECKER		REPORT NO. NOR-59-396
DATE 15 July 1959 Rev. 28 November 1961	Figure 4. Variation of Tensile Properties with Test Temperature	MODEL



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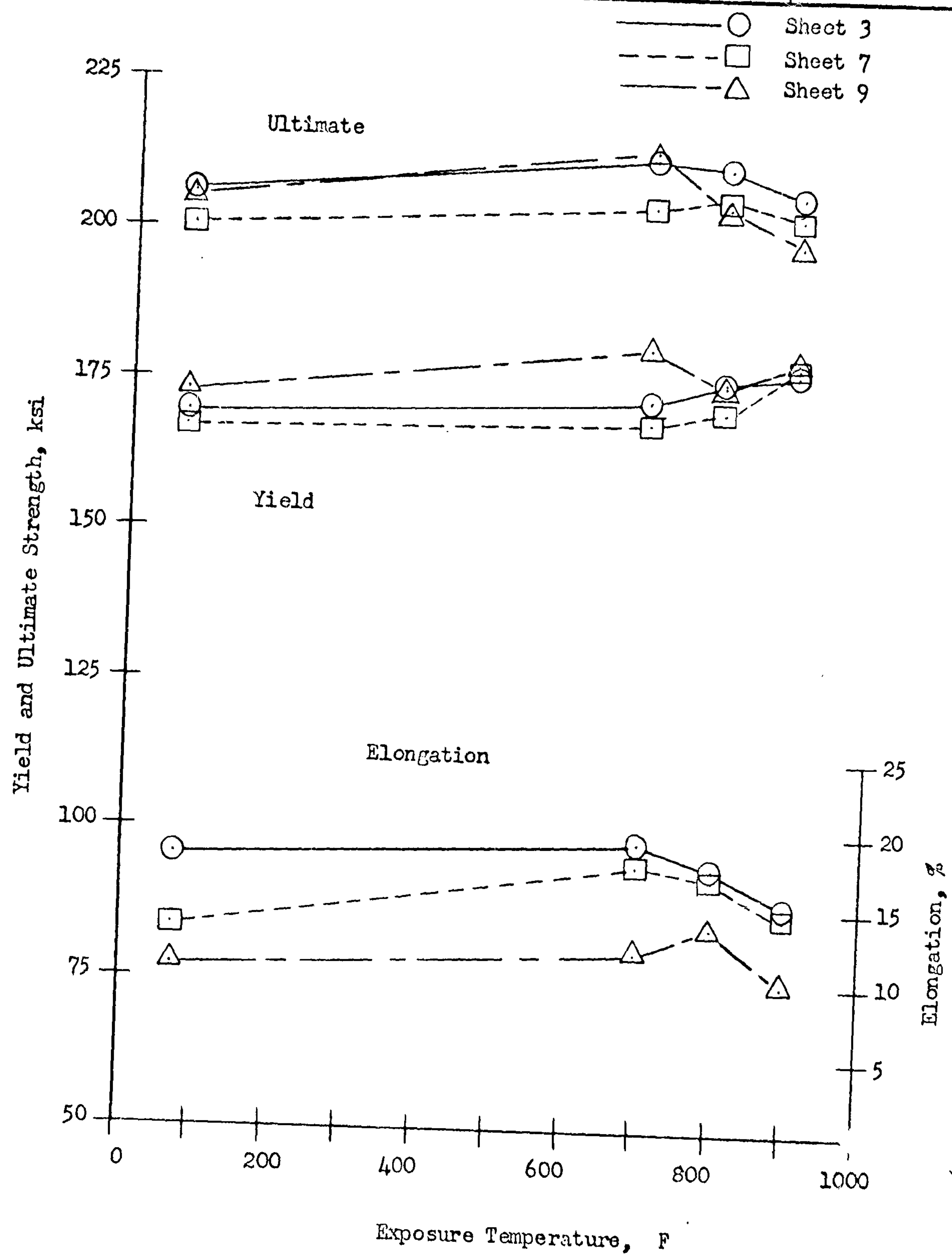
ENGINEER F. C. Kahlbaugh CHECKER	NORTHROP AIRCRAFT, INC. NORTHROP DIVISION	PAGE 19 REPORT NO. NOR-59-396
DATE 15 July 1959 Rev.28 November 1961	Figure 5. Tensile Properties After Exposure to Elevated Temperatures for 100 Hours	MODEL



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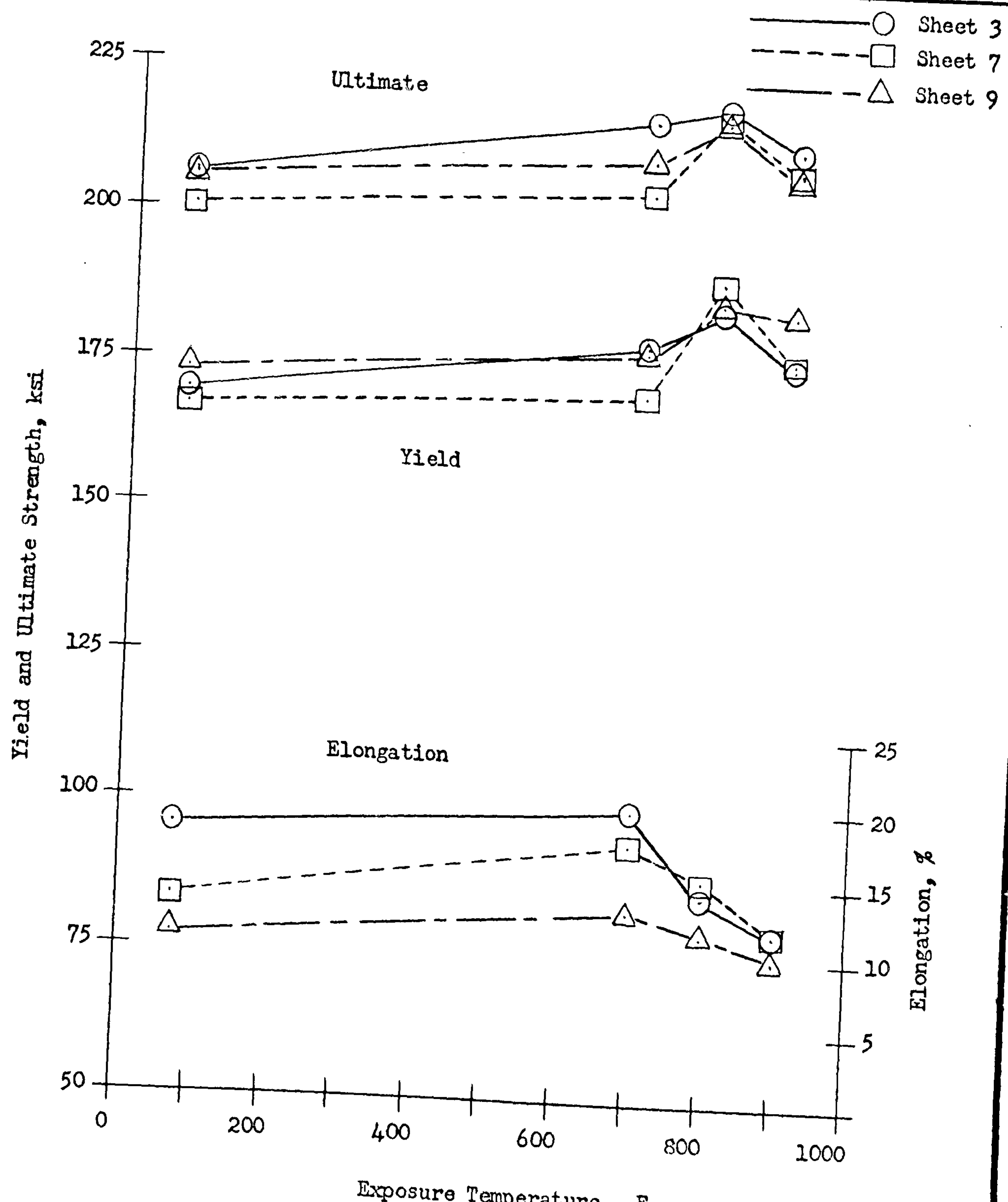
ENGINEER F. C. Kahlbaugh	NORTHROP AIRCRAFT, INC. NORTHROP DIVISION	PAGE 20
CHECKER		REPORT NO. NOR-59-396
DATE 15 July 1959 Rev.28 November 1961	Figure 6. Tensile Properties After Exposure to Elevated Temperatures for 500 Hours	MODEL



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CHECKER		REPORT NO. NOR-59-396
DATE 15 July 1959 Rev.28 November 1961	Figure 7. Variation of Compressive Yield Strength with Test Temperature	MODEL